Defense Technical Information Center Compilation Part Notice

ADP012442

TITLE: Improvement of the U.S. Army Intermediate Cold Wet Boot

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Hard copy only.

This paper is part of the following report:

TITLE: Blowing Hot and Cold: Protecting Against Climatic Extremes [Souffler le chaud et le froid: comment se proteger contre les conditions climstiques extremes]

To order the complete compilation report, use: ADA403853

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP012406 thru ADP012451

Improvement of the U.S. Army Intermediate Cold Wet Boot

Thomas L. Endrusick, B.S.
Research Physical Scientist
Biophysics and Biomedical Modeling Division
U.S. Army Research Institute of Environmental Medicine
Kansas Street
Natick, Massachusetts 01760-5007
USA

Summary

In 1988, the U.S. Army began a program to develop a new combat boot for dismounted soldiers and marines operating in cold and wet environments where the mean monthly temperature ranges between -10° and +20° C. The new Intermediate Cold Wet Boot (ICWB) was designed to fill the protective void between the uninsulated U.S. Army Standard Combat Boot and the highly-insulated U.S. Army Extreme Cold Weather Vapor Barrier Boot. The development of the ICWB has been managed under a unique U.S. Army Pre-planned Product Improvement (P^3I) program that is designed to continuously improve the protective performance of the boot through the rapid integration of proven technological advances in design, fabrication, and materials. Since 1991, numerous changes have been made to the ICWB under this dynamic P^3I process. These include improvements to the boot's outer leather, insulation, waterproof/breathable membrane, insole, and midsole as well as other enhancements to the structure of the basic boot. Since the boot's inception, the Biophysics and Biomedical Modeling Division of the U.S. Army Research Institute of Environmental Medicine has been responsible for extensive biophysical and physiological evaluations of current and prototype versions assessing the potential impact of new technologies on the environmental protective capabilities of the ICWB. The continuous adaptation of improved features to the ICWB has resulted in a boot with a high degree of wearer acceptance within the U.S. military and could serve as a model for future protective clothing procurement by other NATO countries.

Introduction

Every major military conflict since 1700 has recorded the failure of personal equipment issued to combat troops to perform as required. Historical literature from these campaigns is replete with documentation of infantry troops suffering significant losses from the inadequacies of their military-issue protective clothing, especially footwear (1-5).

Military campaigns conducted during periods of prolonged cold-wet weather have usually resulted in a high incidence of non-freezing cold injury (NFCI) to the feet of ground troops wearing footwear incapable of providing sufficient protection relative to the combat theater. During World War II, 87% of all U.S. military cold-induced injuries were incurred by front line infantrymen and in many cases the combat effectiveness of entire infantry units was nullified (1). Furthermore, the effects of combat-induced cold injury in World War II prevented all but 15% of casualties from returning to active duty (1). The high incidence of NFCI (i.e.,"trenchfoot") to the feet of infantry troops in both the Mediterranean and European Theaters of World War II compelled the U.S. Army to initiate a research program aimed at developing footwear that would minimize these types of injuries. This research continues today and is reflected in the development of the footwear system described in this paper.

Cold-induced injury to the human foot has a relationship to the physical environmental factors (i.e., temperature, altitude, precipitation, wind velocity, thawing, terrain, and shelter) in the proximity of the combat theater. NFCI involving the feet can cause recurring circulatory problems and extreme cold sensitivity in many patients. Trenchfoot is characterized pathologically by circulatory, neurologic and sudomotor changes which are expressed by local tissue damage and sterile inflammation. Because the

Paper presented at the RTO HFM Symposium on "Blowing Hot and Cold: Protecting Against Climatic Extremes", held in Dresden, Germany, 8-10 October 2001, and published in RTO-MP-076.

condition affects both nerves and blood vessels, the first sign is loss of sensation in the toes followed by swelling of the foot resulting from rewarming during medical treatment. The foot is sensed to be hot, appears red in color and the swelling can be so great that it is impossible to redress the foot with a boot. The pain which follows is unremitting and is often unaffected even with the use of morphine. A prolonged exposure can result in gangrenous tissue requiring amputation. Whayne and DeBakey reported that numerous soldiers who sustained NFCI to the feet during World War I (1918) were still under the medical care of the Veterans Administration as late as 1949 (1). Despite extensive materials research advances since 1945, many of the longstanding problems associated with the development and eventual procurement of effective military footwear for cold-wet winter use still remain to be resolved.

A large number of infantry troops from the United Kingdom suffered from NFCI while engaged in a 25-day campaign of continuous combat during a traverse of East Falkland Island during May-June, 1982 (6). The prevailing weather during the ground operations was described as classical cold-wet conditions with daily temperatures averaging 0°C, persistent rainfall, and high velocity winds (7).

In 1988, the U.S. Army began development of a new combat boot for dismounted soldiers operating in cold and wet environments. The Intermediate Cold Wet Boot (ICWB) was designed to fill the void between the Standard Combat Boot and the Extreme Cold Weather Vapor Barrier Boot. The ICWB is actively managed under a unique Pre-planned Product Improvement (P^3I) program designed to continuously improve performance through rapid integration of proven technological advances in design, fabrication, and materials.

Since the boot's inception, USARIEM has been responsible for biophysical and physiological evaluations of current and prototype versions to improve the environmental protection provided by the ICWB. Other U.S. military researchers have also made a multitude of material and structural changes to the upper, insole and outsole of the boot. This paper documents over a decade of USARIEM research assisting in the continued improvement of the ICWB.

Biophysical Testing

To date, 46 different prototype boots have been evaluated by USARIEM in a continuous effort to improve the environmental protective capabilities of the ICWB. Test boots have ranged from modified military boots to a variety of commercial outdoor products. Initially, a 1988 market survey produced a boot design that was 26 cm high with a water resistant leather upper, waterproof/breathable protective membrane, synthetic insulation, and lugged rubber outsole. In 1989, 4 military and 7 commercial boots were selected for intensive biophysical testing on the USARIEM Thermal Foot Model (TFM, Figure 1) to establish the thermal insulation range available from this type of footwear under various environmental conditions.

The TFM is a copper, life-sized model of the human foot that measures both localized and total thermal resistance, R ($m^2 \cdot K \cdot W^{-1}$). Power input and the calculation of insulation values for the total foot model and its 29 individual sections are controlled by an automated system. The copper surface of the foot model is controlled at 30°C. Regional thermal resistance (R_r) to heat exchange is calculated using

$$\mathbf{R_r = A_i \cdot T \cdot P^{-1}}$$

where

A_i = area of each regional segment, m^2,
T = temperature gradient between the foot model surface and ambient air temperature, °C, and
P = regional power input, W.

Ideally, three separate samples of the test footwear system are evaluated and the average value is reported. R values can be converted to the more familiar clo unit (1 clo = 0.155 $m^2 \cdot K \cdot W^{-1}$) to establish a ranking order of standard and prototype footwear for downselection and subsequent procurement purposes. The initial TFM testing also assisted in the selection of types of thermal insulation and protective membrane that were chosen for the ICWB.

The first ICWB fielded was close to the original design utilizing Thinsulate™ insulation, a Gore-Tex™ membrane, and a Vibram™ outsole. From the mid 1990's, USARIEM research efforts have

concentrated on reducing overall boot weight while expanding the protective temperature range of the ICWB. To accomplish these goals, extensive TFM testing was done to identify improved, lightweight insulation materials and the optimal amount of insulation the boot could functionally accommodate.

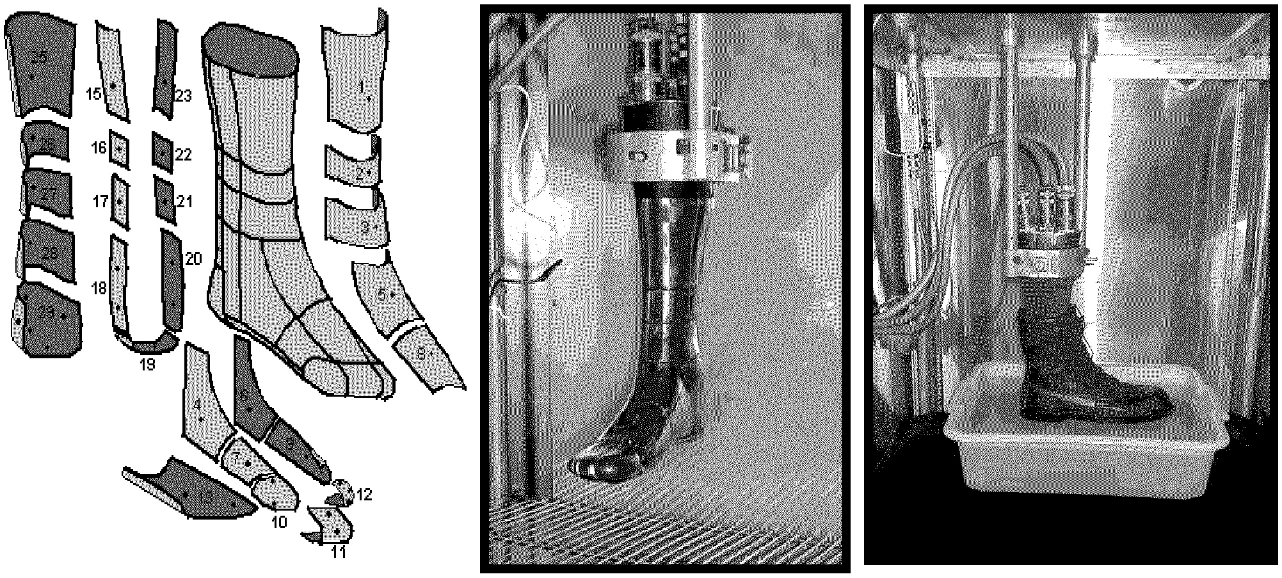

Figure 1. Photographs of the USARIEM Thermal Foot Model (TFM) showing the 29 individual zones (left) and the method of evaluating military footwear for thermal resistance when exposed to external moisture (right).

In 2001, TFM testing assisted in the decision to make a major modification to the ICWB by allowing the insulation to be removable in the form of a separate bootee liner (Figure 2). Personnel will be issued two pairs of bootees and will be able to quickly exchange wetted bootees with dry replacements. This latest version of the boot has a more waterproof leather upper with the Gore-Tex membrane bonded to the inner surface. Changes have also been made to the boot’s tongue with upgraded leather and the entire rubber midsole has been replaced with softer, more flexible polyurethane.

Figure 2. Photograph showing the latest version (2001) of the ICWB with removable insulation liner.

Physiological Testing

In 1990 two commercial and three military boots (Figure 3) downselected from TFM testing were evaluated during controlled wear trials to define human thermophysiological responses at the extreme ends

of the ICWB temperature range (8). Early in the ICWB planning process, military planners were hopeful that an existing service boot could be configured or modified to provide the protection and performance required by the new boot.

Each boot was evaluated under two different scenarios conducted on two consecutive test days. On the first day all test volunteers wore a new pair of the same type boot and attempted to sit for 240 min at an ambient temperature (T_a) of -23.4°C, dew point temperature (T_{dp}) of -34.7°C, and an air velocity (V_a) of 1.7 $m \cdot s^{-1}$ (SIT, Figure 4). This scenario was designed to simulate static military situations such as enemy contact, sentry duty, bivouac, etc. After SIT, the boots were immersed upright in 8 cm of water for approximately 17 h. Subjects donned the same pair of boots and attempted a treadmill walk for 60 min at 1.34 $m \cdot s^{-1}$ followed by sitting for 60 min at T_a=-1.0°C, T_{dp}=-9.4°C, and V_a=1.4 $m \cdot s^{-1}$. This scenario was then repeated for 240 min total exposure (WALK/SIT). It was designed to simulate the effects of a prolonged traverse over wet terrain and observe potential foot cooling caused by wearing wet boots during periods of inactivity. Individual rectal temperature, skin temperature, and heart rate were recorded every minute during the experiment.

Volunteers wore the U.S. Army Extended Cold Weather Clothing System (ECWCS). The ECWCS utilizes the "layered" concept of insulation which is intended to minimize the chances of excessive overheating or rapid cooling by either removal or addition of appropriate system components according to the operational environment. The system consists of four inner layers of synthetic, hydrophobic garments and an outer layer of GORE-TEX-lined parka and trousers. The ECWCS has a thermal resistance, R_c ($m^2 \cdot K \cdot W^{-1}$) =0.56 and a water vapor resistance, R_e ($m^2 \cdot kPa \cdot W^{-1}$)=0.082 when measured on a thermal manikin. All subjects wore a U.S. Army Standard Arctic Mitten Set (R_c=0.37 when measured on a Thermal Hand Model). Total weight of the system less footwear and handwear was 10.1 kg.

Boot 1. Standard-issue U.S. Army Cold-Wet Vapor Barrier Boot, all-rubber construction, wool-felt insulation, 2.89 kg/pr., 26 cm high over the U.S. Army Cushion Sole Sock (Control Boot).

Boot 2. Modified U.S. Army Cold-Wet Vapor Barrier Boot, all-rubber construction, THINSULATE®[2] insulation, 2.49 kg/pr., 30 cm high over the Cushion Sole Sock.

Boot 3. Rocky model #7017, all-leather boot, GORE-TEX®[2] membrane, THINSULATE insulation, 1.77 kg/pr., 25 cm high over the Cushion Sole Sock.

Boot 4. Cocoran model III, all-leather boot, SYMPATEX®[2] membrane, THINSULATE insulation, 2.5 kg/pr., 25 cm high over the Cushion Sole Sock.

Boot 5. Multi-Component Boot System (MCBS), 1.9 kg/pr., 25 cm high, consisting of the U.S. Army Leather Combat Boot over a separate GORE-TEX sock, the U.S Army Ski Mountain Sock, and a thin polypropylene sock.

Figure 3. Physical description of test footwear systems tested during the 1990 physiological test.

In 1998, a second human physiological evaluation was conducted to assess the potential of new microencapsulated phase change materials as a replacement for the Thinsulate insulation currently used in the ICWB (9). These new lightweight insulating materials, purporting to absorb and release body heat through a phase change process have recently appeared on the commercial outdoor clothing, handwear, and footwear markets (10). A phase change material (PCM) can be defined as any material that has the ability to readily absorb and reject heat. Current manufacturing processes allow for specific transition temperatures at which point the latent heat of fusion of the PCM is either absorbed or rejected. For footwear insulation applications, PCM are microencapsulated and then integrated into foams or fibers that are incorporated into the lining of the boot. Encapsulation ensures that the phase change process can be continuously repeated without loss of any PCM. The PCMs evaluated in this study were specifically engineered by the manufacturers to improve the thermal comfort of the human foot during exposure to cold ambient temperatures.

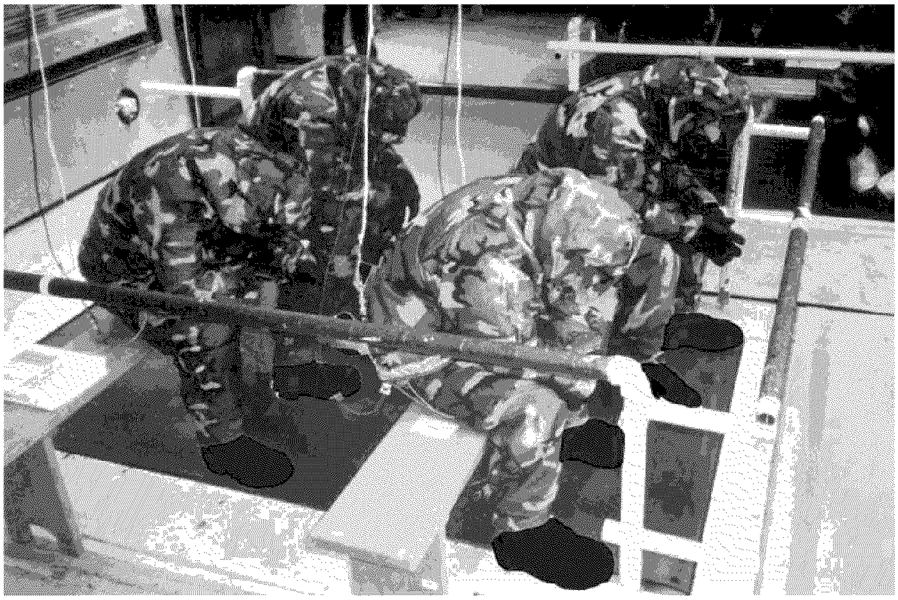

Figure 4. Photograph showing human volunteers during the 1990 ICWB physiological climatic chamber testing.

Eight volunteers wore a modified version of the ECWCS and a new pair of the test boots each day. The basic experiment consisted of walking on a level treadmill for 15 min at 1.34 $m \cdot s^{-1}$, followed by sitting still on a wooden bench for 70 min at 0°C and at -12.3°C. Temperatures of both small toes, both big toes, rectal temperature, and a 3-point mean weighted skin temperature were continuously recorded. Prior to human testing, all four test boots were evaluated for both overall and toe region thermal resistance. The four boots tested were the 1996 standard U.S. Army Intermediate Cold Wet Boot (Control), insulated with 3M Thinsulate™ and three boots identical to the control but insulated with different PCM: Frisby Technologies ComforTemp™ (Boot 1); Gateway Technologies Outlast No. 8088™ (Boot 2); and Outlast Cortina™ (Boot 3). Table 1 describes the test boots in detail regarding identification, physical location, and manufacturer of all protective materials.

Table 1. Identification and physical location of protective material layers for all test boots.

	Foot Skin Surface →	→ →	→ →	→ → Boot Outer Leather
Control Boot	Cambrelle	200 g Thinsulate	Gore-Tex	200 g Thinsulate*
Boot No. 1	Cambrelle	ComforTemp Foam	Gore-Tex	200 g Thinsulate*
Boot No. 2	Cambrelle	Outlast No. 8088	Gore-Tex	200g Thinsulate*
Boot No. 3	Eclipse 200S	Outlast Cortina	Gore-Tex	200 g Thinsulate*

ComforTemp™ phase change foam manufactured by Frisby Technologies, Clemmons, NC USA.
Outlast™ No. 8088 and Cortina™ microencapsulated phase change materials manufactured by Gateway Technologies, Boulder, CO USA.
Thinsulate™ microfilament polyester polyolifin manufactured by 3M Corp., St.Paul, MN USA.
Gore-Tex™ laminate material manufactured by W.L. Gore and Associates, Elkton, MD USA.
Cambrelle™ lining material manufactured by Faytex Corp., Weymouth, MA USA.
Eclipse™ lining material manufactured by Tempo Shain Corp., Salem, MA USA.
*This layer of Thinsulate was located in the upper shaft area only in all test boots.

Results

Since 1988, TFM testing of ICWB prototypes has shown that these types of boots have a range of insulation between 0.210 and 0.330 $m^2 \cdot K \cdot W^{-1}$. Through the TFM testing process, the current version of the ICWB has been modified to contain the optimal weight of Thinsulate insulation (200 gram), has had the Gore-Tex membrane repositioned to the inner surface of the upper and now has the entire insulation package redesigned as a removable bootee.

Table 2 shows overall and localized thermal resistance values from the TFM for the test boots used in the 1990 physiological study. Values given are for dry boot/sock combinations and after an 18 hour immersion in shallow water which effectively simulates a prolonged exposure to wet terrain conditions. Table 2 also shows that boot nos. 3 and 4, utilizing a permanent, internal waterproof/breathable membrane incurred large reductions in overall thermal resistance as a result of an 18 h immersion in 10 cm of water. The water level during immersion was sufficient to cover the entire welt and any adjacent stitching of all test footwear. Similar reductions were also observed in the three toe regions (nos. 10, 11, and 12) that are initial anatomical sites for NFCI. Both boots allowed for the ingression of small amounts of standing water after the immersion. The reduction of thermal insulation due to water ingression can have an immediate impact on wearer comfort as well as subsequent susceptibility to NFCI (11). Boot nos. 1 and 2 that utilized a vapor-barrier (VB) had minimal reductions in thermal resistance as a result of the water immersion and were dry internally after the immersion tests. Boot no. 5 which also utilized W/B in the form of a separate, removable Gore-Tex sock had moderate losses of insulation after immersion. The leather used in the construction of the boot was developed for increased water resistance and allowed no observable water ingression during immersion.

All boots increased in total weight after immersion. The smallest average increases per boot pair was with boots 1 (26 g) and 2 (42 g). Boots 3 (196 g), 4 (444 g), and 5 (147 g) absorbed substantially larger amounts of water.

Table 3 shows that no volunteer was able to endure the desired 4-hour exposure when wearing any of the test footwear while inactive at-23.4°C. Both of the well-insulated, rubber VB boots provided marked increases in ET compared to the three less insulated, leather boots utilizing waterproof/breathable membranes. Analysis of variance (by repeated measures) indicated an overall significant effect of boot type on ET ($F= 29.78$, $p= 0.0001$). Further analysis using Tukey's Studentized Range Test revealed significant differences in ET (boot 1 > boots 3, 4, and 5), (boot 2 > boots 3, 4, and 5). All exposures ($n=39$) were premature due to either voluntary termination by the volunteer as a result of thermal discomfort or a toe temperature measurement reaching predetermined safety limits.

This 1990 human evaluation indicated that only vapor barrier-style military footwear was capable of providing adequate foot protection in simulated cold wet conditions. The three all-leather boots, although utilizing protective membranes claiming to be totally waterproof and vapor permeable, failed to prevent absorption and/or ingression of large amounts of water into the boot after a protracted immersion in shallow water. TFM evaluations indicated that these boots would provide less protection when worn dry and post-immersion. The two vapor-barrier boots afforded increased thermal protection but were not recommended as the new ICWB because they are heavy, awkward to use, and cause the feet to sweat excessively during exercise. Without the implementation of a rigid program of foot hygiene including frequent sock changes, washing and drying of the feet, etc., the potential for maceration of the skin is greatly increased. Furthermore, if the rubber outer shell of a vapor-barrier boot is accidentally punctured by the use of skis, crampons, ice axes, etc., moisture ingression will quickly degrade thermal insulation.

These results prompted U.S. Army footwear developers to intensify their efforts to design an all-new ICWB with much improved waterproof capabilities including treated leather uppers and better waterproof/breathable membrane inserts.

Table 2. 1990 human test footwear-overall and toe region thermal resistance values ($m^2 \cdot K \cdot W^{-1}$) measured on the Thermal Foot Model when dry and after 18 h immersion in 10 cm of water.

	Overall boot			Toe sections		
	Dry	Wet	% change	Dry	Wet	% change
Boot no.						
1	0.283	0.270	-0.05	0.346	0.313	-0.10
2	0.325	0.304	-0.06	0.366	0.313	-0.15
3	0.246	0.179	-0.27	0.234	0.152	-0.35
4	0.241	0.156	-0.35	0.246	0.144	-0.42
5	0.213	0.185	-0.13	0.204	0.160	-0.22

Table 3. 1998 human test-mean endurance time (ET, maximum=240 min) of volunteers wearing five candidate Intermediate Cold-Wet Boots while sedentary (T_a=-23.4°C).

Boot	1	2	3	4	5
ET (min)[a]	125	124	64	81	73
SD	23.7	21.2	17.7	19.7	14.0
Range	103-162	94-165	50-106	65-122	52-95
N	8	7	8	8	8

[a]There was a 51% incidence of premature attrition due to voluntary termination as a result of subject discomfort and a 49% incidence due to T_{sk} (toe) ≤ 5°C.

Table 4. 1998 human test footwear-thermal resistance values (R, $m \cdot K \cdot W^{-1}$) for the overall boot, for toe sections only, and weights (kg) for all test boots.

	Overall-dry	Overall-wet	Toes-dry	Toes-wet	Weight-dry*	Weight-wet*
Control	0.242	0.208	0.233	0.161	1.01	1.12
Boot No. 1	0.237	0.205	0.240	0.167	1.11	1.26
Boot No. 2	0.231	0.205	0.225	0.161	0.99	1.10
Boot No. 3	0.239	0.215	0.233	0.167	1.01	1.11

All dry R values were means of 3 separate evaluations and wet R values from only 1 evaluation.
Wet R values calculated after Thermal Foot Model/test boot immersed upright in 10 cm of water for 18 h.
All boots were size 10 R and tested with the U.S. Army Standard Cushion Sole Sock.
*Weight of right-foot boot only.

Figures 5 and 6 show the time courses of mean small toe temperature during both environmental exposures from the 1998 human test. Time courses of mean big toe temperature displayed similar temperature trends and rank order of test boot/final toe temperature at the end of the exposure. During exercise at 0ºC, toe temperatures generally rose 3-4ºC in all boots while gradually declining during the following 70 min period when the volunteers were sedentary. In general, toe temperatures rose slightly during exercise at –12.3ºC while rapidly declining when volunteers were sedentary. Although mean final T_{st} and T_{bt} values were comparatively high with the Control boot in the 0°C environment, they were consistently

the lowest in the -12.3°C environment. Mean final T_{st} and T_{bt} values were highest in both environments when wearing Boot 1.

Thermal foot model results from the 1998 human test footwear showed that all boots were closely grouped in terms of dry and wet thermal insulation with no particular boot indicating that it would provide an increased level of thermal comfort. The then-current U.S. Army Intermediate Cold-Wet Boot,

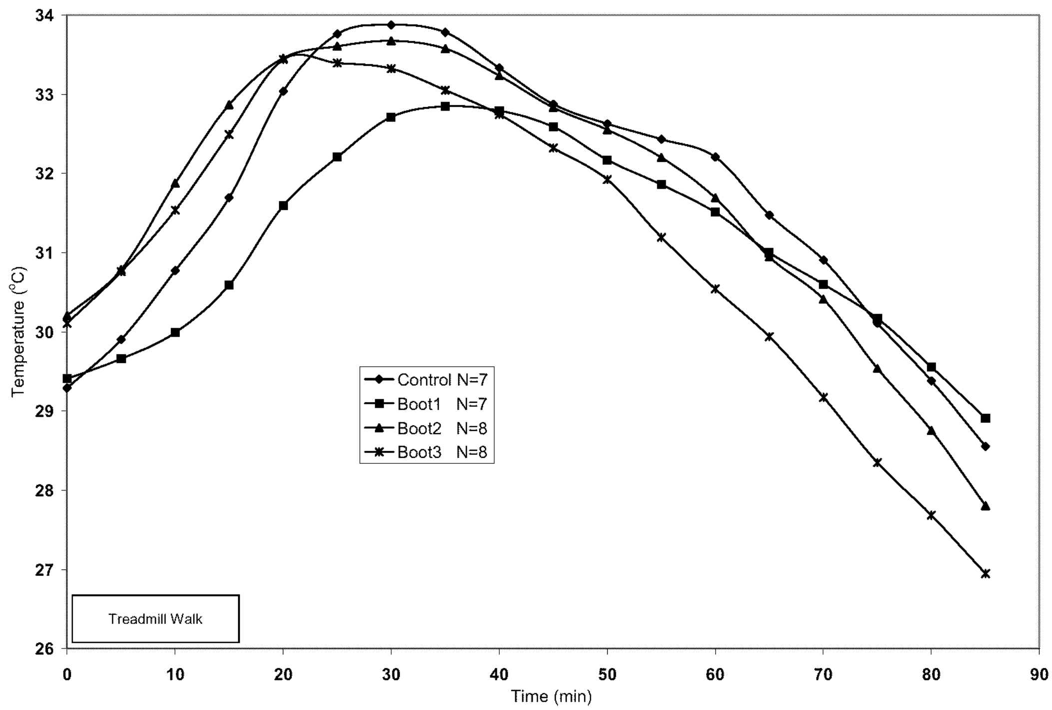

Figure 5. Mean small toe temperature for all test boots at 0° C.

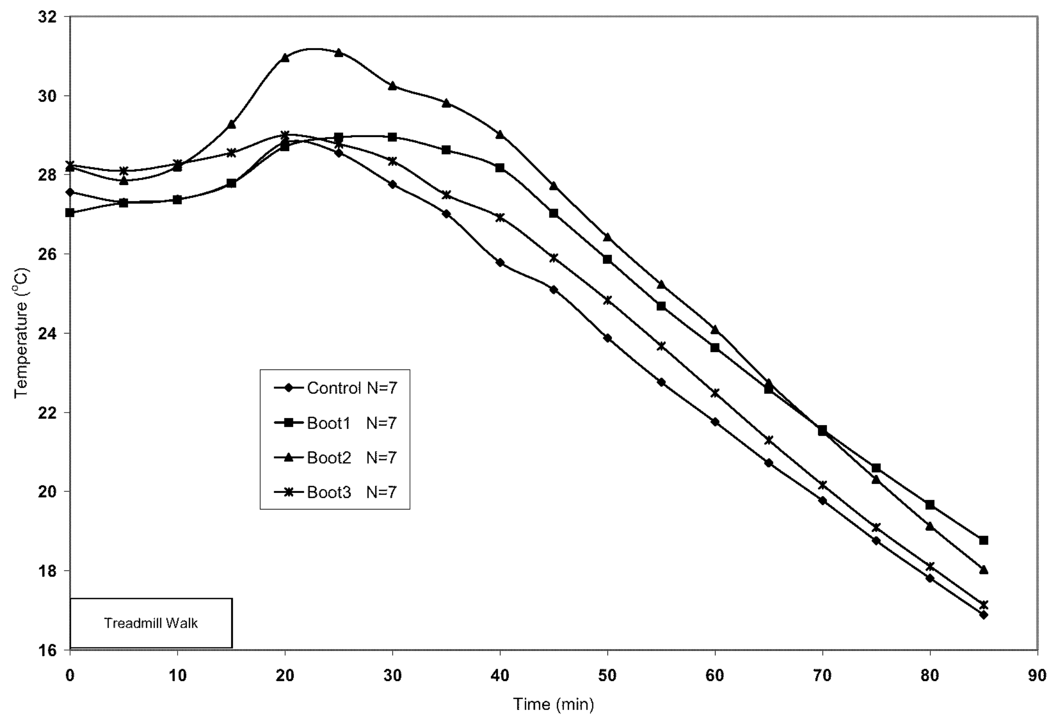

Figure 6. Mean small toe temperature for all test boots at –12.3° C.

issued to personnel operating in cold and wet environments, provided comparatively high toe temperatures at the upper end of the issue temperature range but was less effective at the lower end of the range. Finally, these results suggest that the phase change material in Boot 1 contributed to maintaining both cooler temperatures during exercise and warmer temperatures while sedentary at the skin surface of both the small and large toes. This could provide increased comfort and protection when worn during a more extended cold exposure.

Additionally, the general trend of the Boot 1 temperature curves showed that toe temperatures were cooler during exercise and warmer when volunteers were inactive. These trends also suggest that endurance time would be slightly longer with Boot 1 when compared to the other test boots if the cold exposures had been extended.

Although the current use of PCMs as boot insulation has been rejected, it has been recommended that the U.S. Army continue to evaluate future improvements in these materials designed to increase individual thermal comfort and protection.

Conclusions

The P^3I program, including the biophysical and physiological testing of prototype ICWBs has allowed U.S. Army footwear developers to field a boot which is regularly improved through the inclusion of proven technological advances. TFM and human volunteer testing has contributed greatly in the gradual evolution of the current ICWB. Comfortable, functional footwear is crucial to the success of military operations, especially those involving an extended exposure to cold and wet weather. The British Army's ground operations in the Falkland Islands War showed that a prolonged traverse over rough terrain during cold-wet environmental conditions by well-trained infantry forces wearing even "modern" combat footwear will result in a large percentage of soldiers suffering from serious cold injuries to the feet. Modern land warfare has the potential of being conducted at an increasingly rapid pace across a larger battlefield. Sustained military operations can result in infantry troops advancing far beyond sources of supply in order to achieve strategic objectives. Clean, dry clothing, socks and footwear will probably not be available when needed.

Continuous evaluation of new applications to improve the performance of the ICWB has resulted in an item that provides excellent cold-wet environmental protection along with a high degree of soldier acceptance. The active testing approach characterized by the P^3I program will ensure that the ICWB continues to evolve with the adoption of more effective technologies to maximize warfighter foot protection in cold and wet operational areas.

References

1. Whayne, T.F., and DeBakey, M.E. 1958. Medical Department of the U.S. Army in World War II: Cold Injury, Ground Type. Office of the Surgeon General, Washington, DC, U.S. Government Printing Office.

2. Larrey, D.J. 1814. Memoirs of military surgery and campaigns of the French Armies, on the Rhine, in Corsica, Catalonia, Egypt, and Syria; at Boulogne, Ulm, and Austerlitz; in Saxony, Prussia, Poland, Spain, and Austria, Translated by Richard Wilmott Hall, First American Printing from the Second Paris Edition, Joseph M.Cushing, Baltimore.

3. Thatcher, J. 1862. Military Journal of the American Revolution. Hurlbert Williams and Co., Hartford.

4. Medical and Surgical History of the British Army During War Against Russia in Years 1845-56, His Majesty's Stationary Office, London, 1858

5. Rice, D.G. An evaluation of the supply, utilization and adequacies of winter clothing for the U.S. Army in Korea 1951-52. In Cold Injury-Korea 1951-52, Report 113, Army Medical Research Laboratory, Fort Knox, Kentucky, 1953, pp.141-175.

6. Oakley, E.H.N. 1984. The design and function of military footwear: a review following experiences in the South Atlantic. Ergonomics, 27: 631-37.

7. McCaig, R.H. and Gooderson, C.Y. 1986. Ergonomic and physiological aspects of military operations in a cold wet environment. Ergonomics, 29: 849-57.

8. Endrusick, T., Santee, W., DiRaimo, D., Blanchard, L., and Gonzalez, R. 1992. Physiological responses while wearing protective footwear in a cold-wet environment. In J. McBriarty and N. Henry (eds.), *Performance of Protective Clothing:Fourth Volume, ASTM STP 1133* (American Society for Testing and Materials, Philadelphia). 544-556.

9. Endrusick, T., Brennick, J., Santee, W., and Gonzalez, R. 2000. Microencapsulated phase change materials: thermal insulation applications for military footwear. In proceedings of the 22nd Army Science Conference, Baltimore, MD. 253-255.

10. Maguire, M. and Fosset, T. 1996. Microencapsulated Phase Change Material. Volume 2: Garment Applications. USAF MC Research Report No. WL-TR-96-3143.

11. Endrusick, T. 1996. The contribution of standard military flight boots to the development of non-freezing cold injury. In proceedings of the 7th International Conference on Environmental Ergonomics, Jerusalem, Israel. 299-302.

Disclaimer

The views, opinions, and/or findings contained in this paper are those of the author and should not be construed as an official Department of the Army position, policy, or decision unless so designated by other official documentation. Human volunteers participated in these studies after giving their free and informed voluntary consent. Investigators adhered to U.S. Army Medical Research and Materiel Command (USAMRMC) Regulation 70-25 on Use of Volunteers in Research. Citation of commercial organizations and registered trade names of commercial products in this paper do not constitute an official Department of the Army endorsement or approval of the products or services of the organization. Approved for public release; distribution is unlimited.